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Attorney Docket No. 102605

WELL CONDUCTOR STRAIN MONITORING

[0001] This application claims the benefit of United States Provisional Patent Application Number 61/849,429; filed on June 26, 2013 by the inventor, Dr. Anthony Ruffa and entitled "SUBSEA WELL CONDUCTOR STRAIN MONITORING".

STATEMENT OF GOVERNMENT INTEREST

[0002] The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

[0003] None.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

[0004] The present invention relates to measuring strain and bending stresses in a well conductor, and more particularly to a plurality of Bragg gratings written onto an optical fiber that is integrated into an armored cable wrapped around the well conductor.

(2) Description of the Prior Art

[0005] The well conductor is a primary structural member for a well. As such, it is necessary to accurately understand the loadings that the well conductor is subjected to. Deformation of the conductor can result in significant misalignment of the well axis and production from the well can be lost.

[0006] To monitor the loadings and deformation; measurements must be taken along the length of the conductor. However, attaching sensors directly to the conductor can result in damage to the sensors. What is needed is a system for measuring bending stress in the well conductor without attaching sensors directly to the conductor. The system should also be sufficiently rugged so as to withstand the anticipated loadings. In addition, the system should have sufficient capacity to provide measurement data from the full length of the well conductor.

SUMMARY OF THE INVENTION

[0007] Accordingly, it is an object of the present invention to provide a system for measuring bending stresses in a well conductor, wherein sensors of the system are protected from damage when the well conductor is subjected to loads.

[0008] It is another object of the present invention to provide a measurement system capable of withstanding anticipated loadings on the well conductor.

[0009] It is a still further object of the present invention to provide a well conductor measurement system with the capacity

to provide stress measurement data from the full length of the conductor.

[0010] In accordance with these and other objects made apparent hereinafter, a well conductor strain monitoring system is provided. The system includes a plurality of fiber optic Bragg grating sensors capable of measuring strain. The Bragg gratings are written onto a single optical fiber. The optical fiber is integrated into a steel or synthetic cable that is wrapped around the well conductor.

[0011] The cable consists of steel strands wound around a core containing the optical fiber to form an armored cable to protect the optical fiber. The armored cable is further integrated into a larger steel or synthetic strength cable to sustain the anticipated loads on the conductor. For example, a 3/8" steel cable can withstand working tensions in the thousands of pounds, and is sufficiently ruggedized to protect the fiber from damage.

[0012] The strength cable is then wrapped around the conductor under tension and anchored at both ends. The cable is wound at a prescribed angle so as to have multiple wraps around the conductor. Accordingly, the cable clamp fixtures are oriented at a low helical angle.

[0013] The cable clamps can be either welded directly to the conductor, or secured to a worm gear clamp having a galvanized or stainless steel band with slots, similar to a common hose clamp. Once tensioned, the cable remains stationary against the conductor and holds a position. Strain gages are spaced along the optical fiber, such that the strain gages are oriented 90

degrees apart when the cable is wrapped about the conductor. This orientation supports the estimation of bending in any direction.

[0014] In one embodiment, a conductor strain monitoring system includes an optical fiber. A plurality of evenly spaced Bragg grating sensors can be formed on the fiber. A plurality of cables can be wound about the optical fiber to form a measurement cable.

[0015] The measurement cable is helically wound and tensioned about the conductor at a helical angle. The spacing of the Bragg gratings and the helical angle are configured such that the measurement cable is held in position relative to the conductor and the Bragg grating sensors are spaced radially 90 degrees apart about the conductor.

[0016] The cables include armoring cables wound about the optical fiber and strength cables wound about the armoring cables. A first clamp secures a first end of the measurement cable to the conductor and a second clamp secures the opposite end of the measurement cable to the conductor.

[0017] At least one of the clamps is disposed on the well conductor at the aforesaid helical angle. One or both of the clamps can include a captive screw and a band having threads thereon. The measurement cable is fixed to the band. The screw engages the threads such that rotation of the screw moves the band and the measurement cable in a direction parallel to a longitudinal axis of the measurement cable.

[0018] In one embodiment, the armoring cables are fabricated from either steel or Kevlar. The strength cables may be fabricated from either steel or Kevlar. Also, at least one of the clamps can be configured as a hose clamp.

[0019] In one embodiment, a conductor strain monitoring system includes an optical fiber having a plurality of Bragg grating sensors formed thereon. The grating sensors are spaced evenly along a length of the optical fiber. A plurality of armoring cables can be wound about the optical fiber. A water block material encases the armoring cables and a plurality of strength cables can be wound about the armoring cables.

[0020] The optical fiber, the armoring cables, the water block and the strength cables form a measurement cable. The measurement cable is helically wound and tensioned about the conductor at a angle such that the measurement cable is held in position relative to the conductor and the grating sensors are spaced radially 90 degrees apart about the conductor.

[0021] The system includes a first clamp securing a first end of the measurement cable to the conductor and a second clamp securing a distal end to the conductor. At least one of the first or second clamps is disposed on the conductor at the aforesaid helical angle. One or both of the clamps include a captive screw and a band having threads thereon. The measurement cable is fixed to the band. The screw engages the threads such that rotation of the screw moves the band and the measurement cable in a direction parallel to the longitudinal axis the measurement cable.

[0022] Other objects, features and advantages of the present invention including various novel details of construction and combinations of parts, will now be more particularly described with reference to the accompanying drawings and pointed out in the claims. It will be understood that the particular assembly embodying the invention is shown by way of illustration only and not as a limitation of the invention. The principles and features of this invention may be employed in various and numerous embodiments without departing from the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] Reference is made to the accompanying drawings in which are shown illustrative embodiments of the invention, from which its novel features and advantages will be apparent, wherein corresponding reference characters indicate corresponding parts throughout the several views of the drawings and wherein:

[0024] **FIG. 1** is a partial isometric view of a well conductor strain measurement system;

[0025] **FIG. 2** is a cross-sectional view of an armored and strengthened optical fiber for use in the system of **FIG. 1**; and

[0026] **FIG. 3** is a schematic isometric view of a clamp for use in the system of **FIG. 1**.

DETAILED DESCRIPTION OF THE INVENTION

[0027] Referring now to **FIG. 1**, there is shown a well

conductor **5** having a strain measurement system **10** attached thereto. The strain measurement system **10** includes a measurement cable **12** helically wound on the prior art well conductor **5.** The measurement cable **12** is wrapped around the conductor **5** in tension and is secured to the conductor by clamps **14** at respective ends **12a** and **12b** of the measurement cable.

[0028] The clamps **14** can be affixed to the conductor **5**, such as by welding. The number of turns of the measurement cable **12** around the conductor **5** is determined by a helical angle **α** at which the clamps **14** are fixed to the conductor. Once tensioned, the measurement cable **12** will remain stationary against the conductor **5**.

[0029] Referring now to **FIG. 2**, there is shown a cross-sectional view of the measurement cable **12** taken at line **2-2** of **FIG. 1**. An optical fiber **16** forms the core of the measurement cable **12.** In a manner known to those of skill in the art, Bragg gratings **18** (one of which is shown schematically in **FIG. 2**) are written onto the fiber **16.** The gratings **18** are spaced evenly along a length of the fiber **16.** Spacing of the Bragg gratings **18** along the fiber **16** is based on a helical angle **α** (**FIG. 1**), such that the Bragg gratings align along the length of the conductor **5** (as indicated by location marks **χ** in **FIG. 1**). For measuring bending in each direction; the Bragg gratings **18** are spaced so as to align radially 90 degrees apart on opposite sides of the conductor **5**.

[0030] The equation for a helix around a right circular cylinder is

[0031] $x = a\cos\theta;$

[0032] $y = a\sin\theta;$

[0033] $z = b\theta.$

[0034] Here a is the radius of the right circular cylinder, θ measures angular extent along the circular extent of the cylinder, and $2\pi b$ is the increase in height due to one full helical wrap.The helical angle α is

[0035] $\alpha = \tan^{-1}(2\pi a/b).$

[0036] In a manner known to those of skill in the art, a plurality of the armoring cables **20** (one of which is designated in **FIG. 2**) are wound around the fiber **16** to protect the fiber from damage. Water blocking material **22** covers the armoring cables **20** and the fiber **16**. A plurality of strength cables **24** (one of which is designated in **FIG. 2**) are wound around the blocking material **22** to provide the strength required to withstand anticipated loadings. Two layers of the strength cables **24** are shown for illustration and not for limitation.

[0037] Referring now to **FIG. 3,** there is shown a schematic isometric view of a configuration for clamps **14.** It will be understood that the clamps **14** at the ends **12a** and **12b** may each have different configurations depending on the method used for winding the measurement cable **12** onto the conductor **5.** The configuration of the clamp **14** in **FIG. 3** is in the manner of well-known hose clamps.

[0038] A base **32** of the clamp **14** is fixed to the conductor **5** (not shown in **FIG. 3**). A band **34** is positioned on the base **32** so as to be movable over the base in the directions shown by double arrow **A**. A gear housing **36** is positioned over the band **34** and is affixed to the base **32**. A screw **38** (shown in phantom in **FIG. 3**) is rotatably fixed within the housing **36** and engages threads **34a** of the band **34** (some of which are designated in **FIG. 3**). The measurement cable **12** is fixed at an end **34b** of the band **34,** such that movement in the directions of arrow **A** is parallel to longitudinal axis **X** of the measurement cable. As the screw **38** is rotated; engagement of the screw with the threads **34a** results in movement of the band **34** over the base **32.** Depending on the direction of rotation; the measurement cable **12** can be tensioned about the conductor **5,** or loosened for removal from the conductor.

[0039] What has thus been described is a well conductor strain monitoring system **10** using a plurality of fiber optic Bragg grating sensors **18** written onto a single optical fiber **16.** Armoring cable strands **20** are wound around optical fiber **16** to protect the optical fiber. Armoring cables **20** and optical fiber **16** are further wrapped with strength cables **24** to provide adequate robustness. A layer of water blocking material **22** is placed between the armoring cables and the strength cables.

[0040] The composite cable **12** is then wrapped around the well conductor **5** under tension and anchored at both ends by the clamps **14.** The cable **12** is wound at a prescribed angle (**α**) so as to have multiple wraps around the conductor **5.** Once tensioned, the

composite measurement cable **12** remains stationary against the conductor **5** and holds its position. The Bragg grating strain gages **18** are spaced along the optical fiber **16,** such that the strain gages **18** are oriented 90 degrees apart when the measurement cable **12** is wrapped about the conductor **5** at an angle **α**.

[0041] The cables will be wrapped around the conductor in a helical pattern. The actual bending strain will thus depend on the helical angle. If two cables were along the axis of the conductor, then the bending strain in the plane containing the cables would be the difference in the strains at antipodal points (i.e., oriented 180 degrees apart on the cylinder). However, since the cables are helically wound on the cylinder, the strain along the axis must be computed from the strain measured in the Bragg grating in the helix.

[0042] The component of the unit vector tangent to the helix along the axial direction is $b/\sqrt{a^2+b^2}$, so the strain at the antipodal points would be multiplied by this factor and then subtracted to get the bending strain.

[0043] The strain gages **18** on opposite sides of the conductor **5** move as the conductor bends; thereby, providing a measure of the bending, once the outputs of opposite strain gages are subtracted in the manner known in the art. The strain gages **18** located at opposite sides of the conductor **5** and spaced 90 degrees apart support the estimation of bending in any direction.

The temperature variation across the conductor **5** should be small, such that the effects of temperature should be negligible, being largely subtracted out as well.

[0044] Because the strain gages **18** are integrated into the composite measurement cable **12** and not attached directly to the conductor **5**, the measurements from the Bragg gratings will need to be calibrated to obtain the true bending of the conductor. As is known in the art, testing in a simulated lab environment can lead to the measurements needed for calibration. Once calibrated, the results obtained from the system **10** should be accurate, since the strain in the fiber **16** will translate directly to the measurement cable **12**. The measurement cable **12**, once in place under tension, will move with the conductor **5** as the cable bends.

[0045] The foregoing description of the preferred embodiments of the invention has been presented for purposes of illustration and description only. It is not intended to be exhaustive or to limit the invention to the precise form disclosed; and obviously many modifications and variations are possible in light of the above teaching. For example, the conductor **5** can be other than a well conductor. The system **10** is compatible with many types of pipes or shafts where strain monitoring is needed without mounting strain gages directly to a conductor.

[0046] As a further example, the armoring cables **20** and the strength cables **24** may be fabricated from various materials adequate to protect the fiber **16** and provide strength sufficient to withstand the forces that the conductor **5** is known to be

subjected to. Materials can include, but are not necessarily limited to, steel and Kevlar. Additionally, the armoring cables **20** and the strength cables **24** may each be of different materials, again depending on the known forces and environments that the measurement cable **12** will be subjected to.

[0047] Also, the clamps **14** can each be configured separately. For example, the measurement cable **12** can be anchored by the clamp **14** (as illustrated in **FIG. 3**) at the first end **12a**. The length of the measurement cable **12** can then be wound onto the conductor **5** under moderate tension, and the end **12b** can be securely anchored to the conductor by means of a simple u-shaped clamp welded directly to the conductor. The screw **38** of the clamp **14** at the end **12a** can then be rotated to tighten the measurement cable **12** to a final tension.

[0048] It will be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

What is claimed is:

1. A conductor strain monitoring system, comprising:

an optical fiber having a plurality of Bragg grating sensors formed thereon, said sensors spaced evenly along a length of said fiber; and

a plurality of cables wound about said optical fiber, wherein said fiber and said cables together form a measurement cable, said measurement cable helically wound and tensioned about a conductor at a helical angle such that said measurement cable is held in position relative to the conductor, and wherein said grating sensors are spaced radially 90 degrees apart about the conductor.

2. The system of claim 1, wherein said plurality of cables comprise:

a plurality of armoring cables wound about said optical fiber; and

a plurality of strength cables wound about said armoring cables.

3. The system of claim 2, further comprising a first clamp securing a first end of said measurement cable to the conductor and a second clamp securing a distal end of said measurement cable to the conductor.

4. The system of claim 3, wherein at least one of said first and second clamps is disposed on said conductor at the helical angle.

5. The system of claim 4, wherein at least one of said first and second clamps comprise:

a captive screw; and

a band having threads thereon, said measurement cable being fixed to said band, said screw engaging said threads such that rotation of said screw moves said band and said measurement cable in a direction parallel to a longitudinal axis of said measurement cable.

6. The system of claim 2, wherein said plurality of armoring cables are fabricated from at least one of steel and Kevlar.

7. The system of claim 6, wherein said plurality of strength cables are fabricated from at least one of steel and Kevlar.

8. The system of claim 4, wherein at least one of said first and second clamps comprise a hose clamp.

9. A conductor strain monitoring system, comprising:

an optical fiber having a plurality of Bragg grating sensors formed thereon, said Bragg grating sensors spaced along a length of said optical fiber;

a plurality of armoring cables wound about said optical fiber;

a water block encasing said plurality of armoring cables; and

a plurality of strength cables wound about said armoring cables, wherein said optical fiber, said armoring cables, said water block and said plurality of strength cables together form a measurement cable, said measurement cable helically wound and tensioned about a conductor at a helical angle such that said measurement cable is held in position relative to the conductor, and wherein said grating sensors are spaced radially 90 degrees apart about the conductor.

10. The system of claim 9, wherein said plurality of armoring cables are fabricated from at least one of steel and Kevlar.

11. The system of claim 10, wherein said plurality of strength cables are fabricated from at least one of steel and Kevlar.

12. The system of claim 11, further comprising:

a first clamp securing a first end of said measurement cable to the conductor; and

a second clamp securing a distal end of said measurement cable to the conductor.

13. The system of claim 12, wherein at least one of said first and second clamps is disposed on the conductor at the helical angle.

14. The system of claim 13, wherein at least one of said first and second clamps comprise:

a captive screw; and

a band having threads thereon, said measurement cable being fixed to said band, said screw engaging said threads

such that rotation of said screw moves said band and said measurement cable in a direction parallel to a longitudinal axis of said measurement cable.

15. The system of claim 14, wherein said plurality of armoring cables are fabricated from at least one of steel and Kevlar.

16. The system of claim 15, wherein said plurality of strength cables are fabricated from at least one of steel and Kevlar.

WELL CONDUCTOR STRAIN MONITORING

ABSTRACT OF THE DISCLOSURE

A well conductor strain monitoring system is provided which includes a plurality of fiber optic Bragg grating sensors written onto a single optical fiber. Cable strands are wound around the optical fiber to form an armored cable protecting the fiber. The armored cable is further integrated into a strength cable to provide robustness. This strength cable is then wrapped around the conductor under tension and anchored at both ends. The cable is wound at a prescribed angle so as to have multiple wraps around the conductor. Once tensioned, the cable remains stationary against the conductor and holds a position. The strain gages are spaced along the optical fiber, such that the strain gages are oriented 90 degrees apart when the cable is wrapped about the conductor. This orientation supports the estimation of bending in any direction.

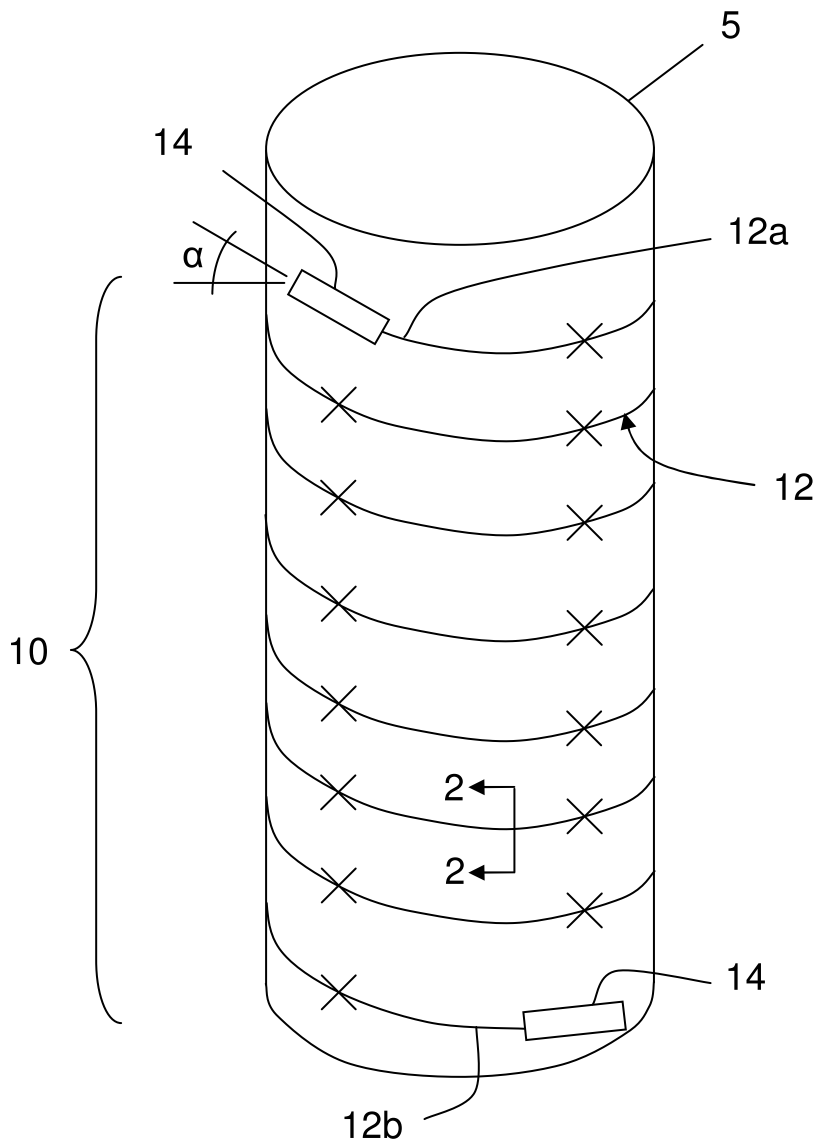

FIG. 1

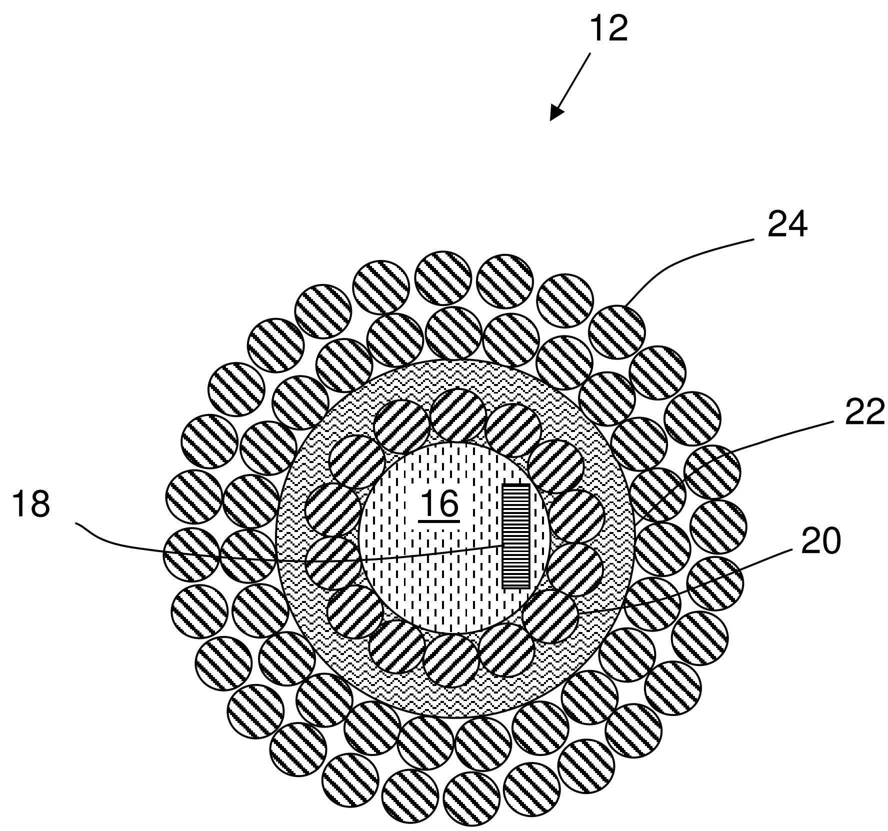

FIG. 2

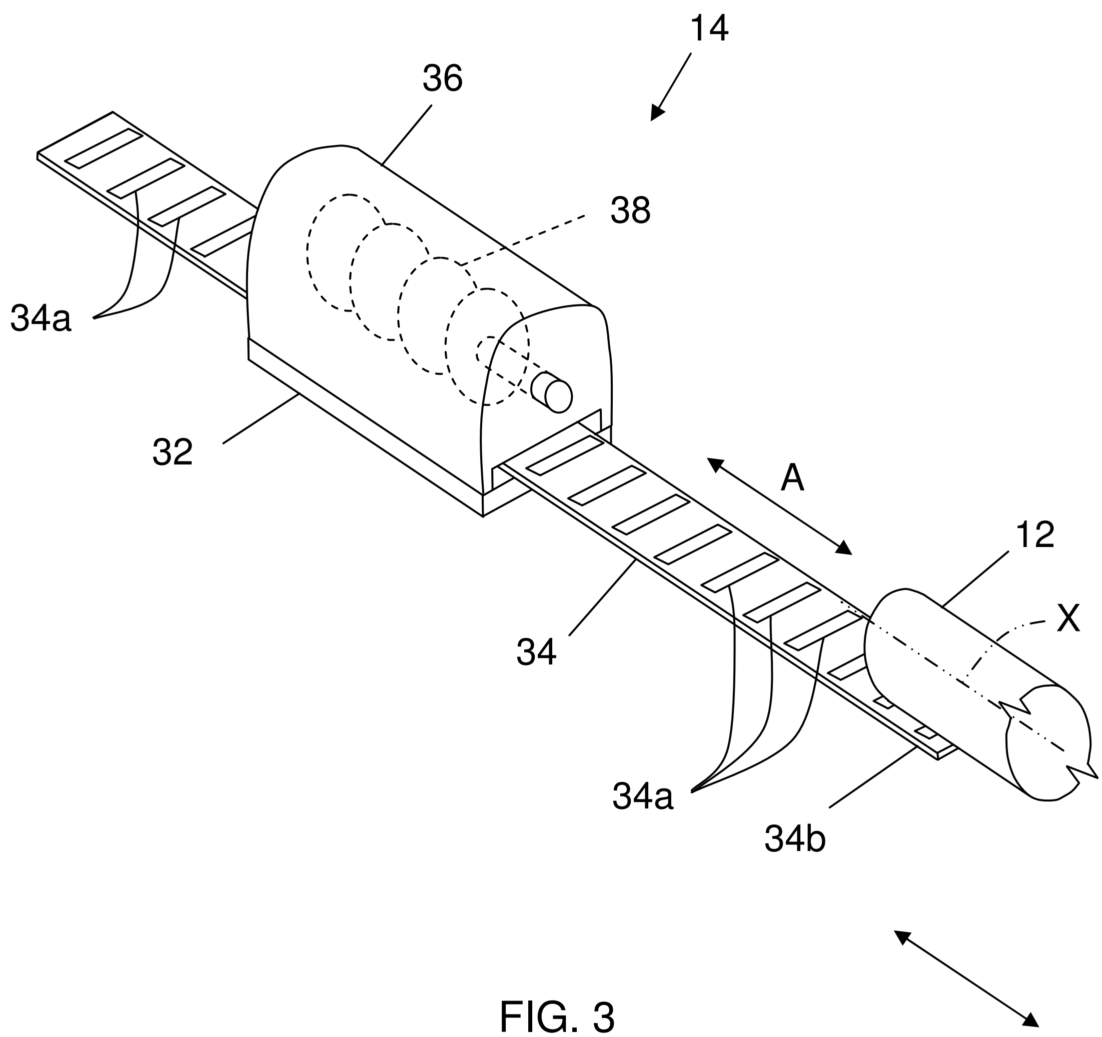

FIG. 3